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CDF

Recent Results from CDF

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We first present recent CDF results on the top quark, covering the measurement of the $t\bar{t}$ production cross section and the top quark mass, the observation of hadronic W decays in top events, the measurement of V_{tb}, the search for flavor changing neutral current decays, and kinematical properties of $t\bar{t}$ production. Then we present one topic from CDF exotic physics results, *i.e.*, the search for first-generation leptoquarks, and one topic from CDF B physics results, *i.e.*, the measurement of time-dependent B^0-$\bar{B}^0$ mixing. Finally we conclude by briefly mentioning the prospects for Run II.

1 Top Quark Physics

At the Tevatron, top quarks are predominantly produced in $t\bar{t}$ pairs by the $q\bar{q}$ annihilation subprocess $q\bar{q} \to t\bar{t}$. Recent theoretical calculations [1] predict the $t\bar{t}$ production cross section to be around 5 pb. In the Run I, CDF has collected data exceeding 100 pb^{-1} of integrated luminosity, in which one can expect about 500 $t\bar{t}$ pairs produced. This is a large number in itself, but it is a tiny fraction of $p\bar{p}$ collisions ($\sim 10^{-10}$) and is less than one thousandth of W production, making it a challenging task for experimenters to isolate the top signal. Single top production through Wg fusion and W^* production is about 45% of this rate, and has not yet been observed.

1.1 Detecting the Top Quark

A top quark produced immediately decays into a W boson and a b quark: $t \to Wb$ and $\bar{t} \to W\bar{b}$. We categorize top decays into three channels by how the two W bosons decay. In the dilepton channel, both W's decay leptonically ($W \to l\nu$), resulting in a final state of $l^+\nu l^-\nu b\bar{b}$. In the lepton + jets channel, one W decays leptonically and the other decays hadronically ($W \to q\bar{q}'$), resulting in a final state of $l\nu q\bar{q}' b\bar{b}$. In the all-hadronic channel, both W's decay hadronically, resulting in a final state of $q\bar{q}'q\bar{q}'b\bar{b}$. In the following, rather than talking on every analysis, I will focus on the lepton + jets analysis [2] and show the results only for the dilepton [3] and all-hadronic [4] analyses.

The signature of the lepton + jets channel is one isolated high transverse momentum ($\mathrm{P_T}$) lepton (e or μ), missing transverse energy ($\not{E}_{\mathrm{T}}$), and 4 jets, 2 of which are from b quarks and 2 from $W \to q\bar{q}'$. In the event selection, we require that there is an e with transverse energy $E_T > 20$ GeV or a μ with $P_T > 20$ GeV/c in the pseudorapidity region $|\eta| < 1.0$, that $\not{E}_T > 20$ GeV, and that there are at least three jets with $E_T > 15$ GeV in $|\eta| < 2.0$. We find 324 events after the event selection. The signal over background ratio is about 1/4 at this stage of data reduction. The major source of background is direct W production in association with jets: $p\bar{p} \to W +$jets. Further suppression of the background is done by identifying jets coming from b quarks. We use two techniques for that. In the SVX tagging, we use the Silicon vertex detector to identify a secondary vertex from a b quark decay. In the soft lepton tagging (SLT), we identify an additional lepton (e or μ) from b quark semileptonic decays.

In the SVX analysis, the efficiency for tagging at least one b quark in a $t\bar{t}$ event with ≥ 3 jets is $39 \pm 3\%$. The most important source of background is direct W production in association with b or c quark jets: $Wb\bar{b}$, $Wc\bar{c}$, Wc. To estimate these backgrounds, we use the HERWIG and VECBOS Monte Carlo to predict the fraction of heavy quarks in the $W+$jet events, and apply these fractions and a tagging efficiency for each type of event to the measured number of $W+$jet events. Including other backgrounds (mistags, non-W, single top, WW, WZ, and Drell-Yan), the total background expected is 9.2 ± 1.5 tagged events. We observe 34 SVX-tagged events (42 SVX tags).

In the SLT analysis, the efficiency for finding an additional e or μ from a b quark decay in a $t\bar{t}$ event with ≥ 3 jets is $18\pm2\%$. The dominant background is mistags and $Wb\bar{b}$, $Wc\bar{c}$ events. We use the measured fraction of tags per track in a sample of generic jets ($p\bar{p} \to$ jets), and apply these fractions to tracks in the $W+$jet events. Other backgrounds come from WW, WZ, non-W, $Z \to \tau\tau$, single top, Wc, and Drell-Yan. The total background expected is 22.6 ± 2.8 tagged events. We observe 40 SLT-tagged events (44 SLT tags). Of the 40 SLT-tagged events, 11 are also SVX-tagged.

1.2 $t\bar{t}$ Production Cross Section

The $t\bar{t}$ production cross section for each analysis channel is given by

$$\sigma = \frac{N - B}{\epsilon_{\mathrm{total}}\mathcal{L}}, \tag{1}$$

where N is the number of observed events, B is the number of expected background events, $\mathcal{L} = 109 \pm 7$ pb^{-1} is the integrated luminosity, and $\epsilon_{\mathrm{total}}$ is the total acceptance consisting of the b tagging efficiency, the geometric and kinematic acceptances including the branching fraction, and the trigger efficiency. See Table 1. The acceptances are calculated for $M_{\mathrm{top}} = 175$ GeV/c^2.

Table 1: CDF $\sigma_{t\bar{t}}$ measurements.

	Lepton+Jets		Dilepton	All-Hadronic	
Tag	SVX	SLT	not req.	SVX	2 SVX
$\epsilon_{\rm tag}$	0.39 ± 0.03	0.18 ± 0.02	–	0.42 ± 0.04	0.11 ± 0.02
$\epsilon_{\rm geo\cdot kin}$	0.104 ± 0.010		0.0076 ± 0.0008	0.106 ± 0.021	0.263 ± 0.045
$\epsilon_{\rm trigger}$	0.90 ± 0.07		0.98 ± 0.01	$0.998^{+0.002}_{-0.009}$	
$\epsilon_{\rm total}$	0.037 ± 0.005	0.017 ± 0.003	0.0074 ± 0.0008	0.044 ± 0.010	0.030 ± 0.010
N	34	40	9	187	157
B	9.2 ± 1.5	22.6 ± 2.8	2.4 ± 0.5	142 ± 12	120 ± 18
σ(pb)	$6.2^{+2.1}_{-1.7}$	$9.2^{+4.3}_{-3.6}$	$8.2^{+4.4}_{-3.4}$	$9.6^{+4.4}_{-3.6}$	$11.5^{+7.7}_{-7.0}$

The results from the dilepton and all-hadronic analyses are also presented in Table 1. The dilepton analysis is clean enough that we do not require b tagging to isolate $t\bar{t}$. There are two paths in the all-hadronic analysis, one requiring a single SVX tagged jet plus kinematic cuts and one requiring two SVX tagged jets.

We combine the results from each analysis using a maximum-likelihood method, taking account of correlated systematic uncertainties. Combining the SVX and SLT analyses, we have $6.7^{+2.0}_{-1.7}$ pb. Combining the two analyses in the all-hadronic channel, we have $10.1^{+4.5}_{-3.6}$ pb. Combining all the analyses, we have $\sigma_{t\bar{t}} = 7.6^{+1.8}_{-1.5}$ pb, where the error includes both statistical (± 1.2 pb) and systematic effects. Figure 1 shows the combined cross sections in comparison with theory. There are three recent calculations [1] using NLO matrix elements and a resummation of the leading soft gluon corrections to all orders. The theory point [4.7 − 5.5 pb] in the figure indicates the spread in the central values of the three predictions. Refer to a talk by Berger [5] at this symposium.

In measuring the cross section in the lepton + jets, dilepton, and all-hadronic channels, we have assumed Standard Model values for the branching fractions, $B_{\rm SM}$, to obtain the cross section σ for each channel. Since $B_{\rm SM}\sigma$ is a measured value for $\sigma \cdot B$ for a given channel, we can extract the top $\rightarrow$ lepton branching fraction from our measurements. Define f as the branching fraction for a top to decay to a lepton in the final state, where lepton universality is assumed. Then the branching fractions for a $t\bar{t}$ pair to decay into the lepton + jets, dilepton, and all-hadronic channels are $2(2f)(1-3f)$, $(2f)^2$, and $(1-3f)^2$. From the ratio of the $B_{\rm SM}\sigma$'s in the three channels, we measure $f = 0.094 \pm 0.024$, consistent with the Standard Model expectation of 1/9.

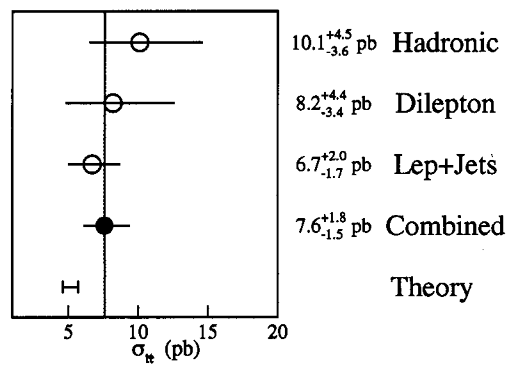

Figure 1: CDF $\sigma_{t\bar{t}}$ measurements.

1.3 Top Quark Mass

CDF has measured the top quark mass in the lepton + jets, [6] dilepton, [3] and all-hadronic channels. [4] Again, I will focus on the lepton + jets analysis.

For the mass measurement in the lepton + jets channel, we select events with at least 4 jets from the lepton + $\geq$ 3 jet sample. To increase the acceptance, we relax the $\mathrm{E_T}$ requirement on the fourth jet to $E_T > 8$ GeV, as compared to 15 GeV on the first three jets, provided one of the four leading jets is tagged by SVX or SLT.

We fit each event to the hypothesis of $t\bar{t}$ production followed by decay in the lepton + jets channel:

$$\begin{aligned} p\bar{p} &\rightarrow t\bar{t} + X \\ t &\rightarrow W^+ b \rightarrow l^+ \nu b \quad \text{or} \quad q\bar{q}' b \\ \bar{t} &\rightarrow W^- \bar{b} \rightarrow q\bar{q}' \bar{b} \quad \text{or} \quad l^- \bar{\nu} \bar{b} \end{aligned} \tag{2}$$

We know the four-momentum of the lepton and the transverse (x, y) components of X. Putting aside the ambiguity in how to assign 4 jets to 4 quarks, we know the four-momenta of 4 quarks, where we set $m_q = m_{\bar{q}'} = 0.5$ GeV/c^2 and $m_b = 5$ GeV/c^2. Then we can reconstruct an event once we know three unknowns: the transverse (x, y) and longitudinal (z) components of the neutrino. In the fitting, five constraints can be applied:

$$\begin{aligned} P_{x,y}(t\bar{t} + X) &= 0 \\ M_{l\nu} = M_{q\bar{q}'} &= M_W \\ M_t &= M_{\bar{t}} \end{aligned} \tag{3}$$

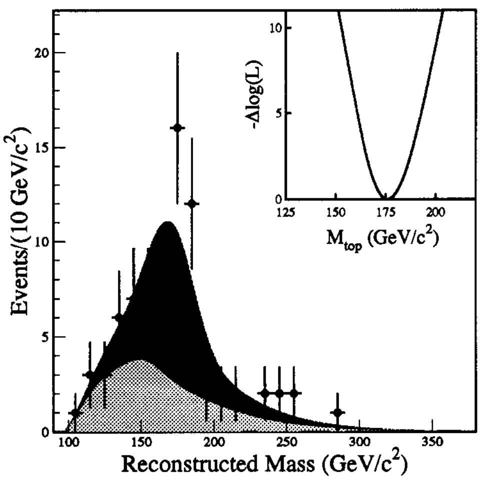

Figure 2: Combined $M_{\rm rec}$ distribution of the four subsamples.

and we use a standard χ^2-minimization technique - 2C fit. The output of each event fit is a reconstructed top mass $M_{\rm rec}$ and a χ^2 of the fit. There are 12 distinct ways of assigning 4 jets to 4 quarks plus a quadratic ambiguity in the determination of $P_z(\nu)$, yielding 24 configurations for reconstructing an event. We require that SVX or SLT tagged jets be assigned to b quarks and choose the configuration with lowest χ^2.

With a sample of $M_{\rm rec}$'s so determined, we use a maximum-likelihood method to fit the $M_{\rm rec}$ distribution to a sum of $t\bar{t}$ Monte Carlo (HERWIG) + background (VECBOS) and extract the top mass $M_{\rm top}$.

The precision with which to measure $M_{\rm top}$ depends on the S/B in the sample and varies between samples with different b tagging requirements. We divide the mass sample into 4 non-overlapping subsamples: events with two SVX tags, events with a single SVX tag, events with an SLT tag and no SVX tag, and events with no tag, but with the tighter $\rm E_T$ requirement of 4 jets with $E_T \geq 15$ GeV. We fit the $M_{\rm rec}$ distributions in each of the four subsamples and then combine the results. The combined $M_{\rm rec}$ distribution is shown in Figure 2. From this we measure $M_{\rm top} = 175.9 \pm 4.8(\text{stat.})$ GeV$/c^2$.

The systematic uncertainties in the top mass measurement in the lepton + jets channel arise from jet energy measurement (4.4 GeV$/c^2$), initial and final state gluon radiation (1.8 GeV$/c^2$), shape of background spectrum (1.3 GeV$/c^2$), b-tagging bias (0.4 GeV$/c^2$), and parton distribution function (0.3 GeV$/c^2$). The total systematic uncertainty is 4.9 GeV$/c^2$. The largest uncertainty comes from jet energy corrections for losses in cracks between detector components, absolute energy scale, contributions from the underlying event,

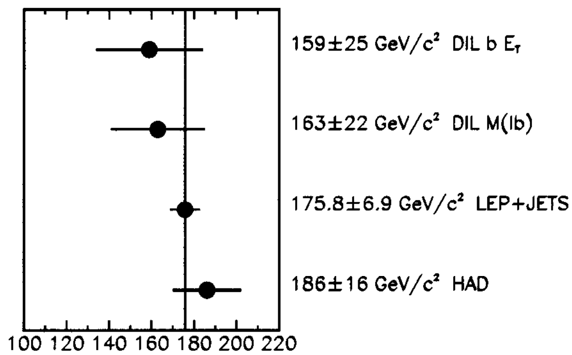

Figure 3: CDF $M_{\rm top}$ measurements.

and losses outside the clustering cone.

CDF has measured the top mass in the dilepton [3] and all-hadronic [4] channels also. In Figure 3 we show a summary of the CDF $M_{\rm top}$ measurements. There are two analyses in the dilepton channel, one using the b-jet $\rm E_T$ distribution and one using the lepton + b invariant mass distribution. The dilepton and all-hadronic results are consistent with the lepton + jets result.

1.4 Hadronic W Decays

In the mass measurement, the dijet mass $M_{q\bar{q}'}$ was constrained to the W boson mass. CDF [7] has observed a dijet mass peak consistent with the W decay in the lepton + 4 jet events. There are two analyses, using different selection cuts to enhance the $t\bar{t}$ content in the sample. In the first analysis, we do not use the b tag information but we apply a kinematic cut requiring that $H_T > 310$ GeV, where $H_T = E_T(l) + \not{E}_T + \sum E_T(\text{jets})$. The dijet mass distribution is shown in Figure 4. There are six combinations per event in forming a dijet mass out of the four jets, resulting in a large combinatorial background. The non-$t\bar{t}$ background is mostly due to W + jets direct production.

In the second analysis, we use double b-tagged events in the lepton + 4 jet sample. In this case there is no ambiguity in jet assignment and further suppression of non-$t\bar{t}$ background is achieved. Combining the two results, we measure the hadronic W mass to be $77.2 \pm 3.5(\text{stat.}) \pm 2.9(\text{syst.})$ GeV/c^2, consistent with the W boson mass.

The inset of Figure 4 (right) shows a scatter plot of the lepton + $\not{E}_{\rm T}$ transverse mass versus the dijet mass. We see most of the events lying in a

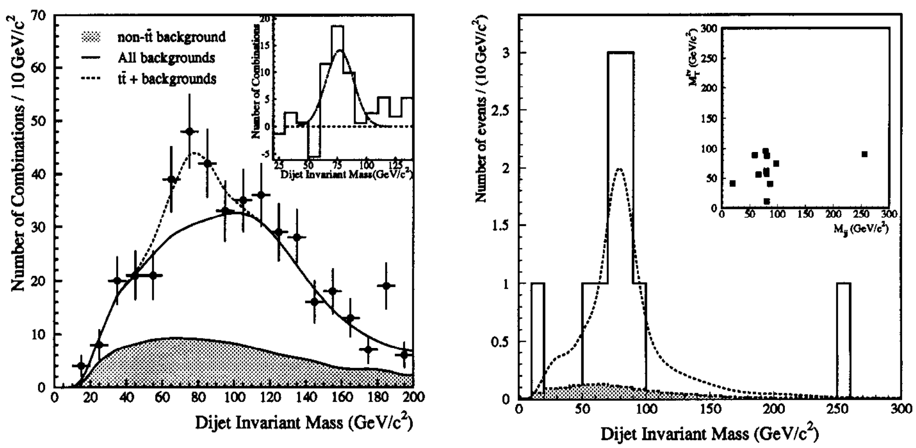

Figure 4: The dijet mass distributions for (left) lepton + 4 jet events with $H_T > 310$ GeV cut and (right) double b-tagged lepton + 4 jet events.

region expected for W bosons. This demonstrates that there are indeed 2 W bosons plus 2 b jets in the event, *i.e.*, CDF top events contain a $2W2b$ state exactly expected for a $t\bar{t}$ pair.

1.5 V_{tb} and Flavor Changing Neutral Current Decays

Unitarity of the CKM matrix implies that $|V_{tb}|$ is very close to 1.0 (0.9989 to 0.9993). CDF has analyzed the lepton + jets and dilepton samples to measure the ratio of events with 0, 1, and 2 b-tags and use this to extract the branching fraction for a top to decay to a b in the $t \to Wq$ decays:

$$B = \frac{BR(t \to Wb)}{BR(t \to Wq)}. \tag{4}$$

In the three-generation Standard Model, we have

$$B = \frac{|V_{tb}|^2}{|V_{td}|^2 + |V_{ts}|^2 + |V_{tb}|^2} = |V_{tb}|^2. \tag{5}$$

The basic idea for measuring B is as follows. Consider a simplified case where there is a single tagging algorithm of efficiency ϵ and no background. The numbers of doubled tagged, single tagged, and untagged events are: $N_2 \propto (B\epsilon)^2$, $N_1 \propto 2B\epsilon(1-B\epsilon)$, and $N_0 \propto (1-B\epsilon)^2$. Then B is given in terms of ratio N_1/N_2 or N_0/N_1 or N_0/N_2 as $B = 2/[\epsilon(N_1/N_2+2)]$ or $1/[\epsilon(2N_0/N_1+1)]$ or $1/[\epsilon(\sqrt{N_0/N_2}+1)]$.

In the actual analysis, we use a maximum-likelihood method combining all information (lepton + 4 jet and dilepton events, SVX and SLT tags) and obtain $B = 0.99 \pm 0.29$. Assuming the three-generation unitarity, this yields $|V_{tb}| = 0.99 \pm 0.15$.

Within the Standard Model, the flavor changing neutral current decays of the top quark are suppressed at the level of 10^{-10} to 10^{-12}. Any appearances of such decays would signal non-Standard-Model physics. CDF [8] has searched $t\bar{t}$ events for one top decaying in the standard fashion ($t \to Wb$) and the other top decaying to a rare mode: $t \to \gamma c$, $t \to \gamma u$, $t \to Zc$, $t \to Zu$. A search for $t \to \gamma q$ in the channels γ + 4 jets and $\gamma + l + \not{E}_T$ + 2 jets yields $BR(t \to \gamma c) + BR(t \to \gamma u) < 3.2\%$ (95% C.L.). A search for $t \to Zq$ in the channel l^+l^- + 4 jets yields $BR(t \to Zc) + BR(t \to Zu) < 33\%$ (95% C.L.).

1.6 Kinematic Properties of Top Production

Kinematic variables which describe $t\bar{t}$ production are compared with a Monte Carlo calculation. The data sample used is lepton + 4 jet events after applying a $\chi^2 < 10$ cut on the mass fitting. In the Monte Carlo, we use HERWIG ($M_{\rm top}$ = 175 GeV/c^2) for top signal and VECBOS W + 3 jets followed by HERPRT for background. We focus on the following variables: invariant mass of t and $\bar{t}$, $\rm P_T$ of $t\bar{t}$ system, $\rm P_T$ of top (semileptonically decaying top and hadronically decaying top), $\Delta\phi$ between t and $\bar{t}$, rapidity of top, rapidity of $t\bar{t}$ system, rapidity difference between t and $\bar{t}$. At the present level of statistics, all distributions are consistent with Monte Carlo calculations. As an example, the $t\bar{t}$ invariant mass distribution and the $t\bar{t}$ system $\rm P_T$ distribution for b-tagged lepton + 4 jet events are shown in Figure 5.

1.7 Summary of CDF top quark physics

(1) The top quark has been observed and the top production cross section has been measured in the lepton + jets, dilepton, and all-hadronic channels. The combined cross section for $M_{\rm top}$ = 175 GeV/c^2 is:

$$\sigma_{t\bar{t}} = 7.6^{+1.8}_{-1.5} \ \ \text{pb.} \tag{6}$$

Recent QCD predictions range from 4.7 to 5.5 pb.

(2) The top quark mass has been measured in the lepton + jets, dilepton, and all-hadronic channels. The three measurements are consistent with each other. The lepton + jets result is the most accurate and it is:

$$M_{\rm top} = 175.9 \pm 4.8(\text{stat.}) \pm 4.9(\text{syst.}) \ \ \text{GeV}/c^2. \tag{7}$$

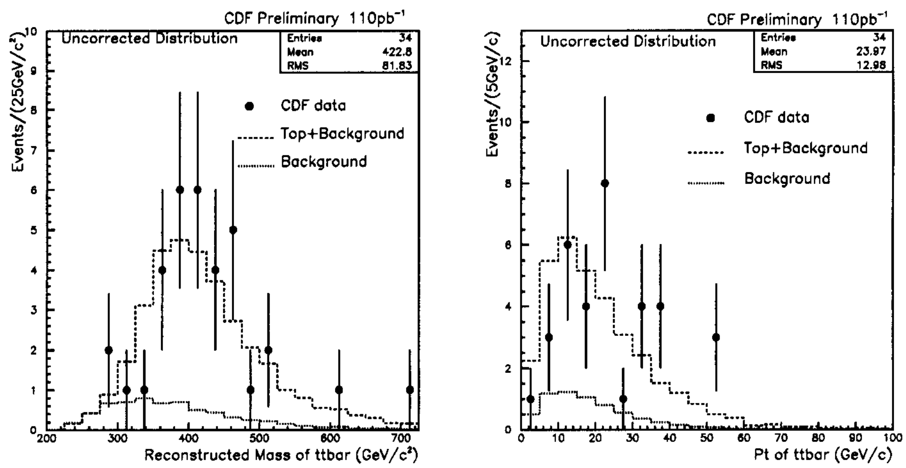

Figure 5: (left) The $t\bar{t}$ invariant mass distribution and (right) the $t\bar{t}$ system $\mathrm{P_T}$ distribution for b-tagged lepton + 4 jet events.

(3) The various properties of the top quark so far measured are consistent with Standard Model predictions.

In the above I have talked only on CDF results. For a recent review of top quark physics including D0 results, refer to a talk by Parke[9] at this symposium.

2 Search for First-Generation Leptoquarks

Leptoquarks are hypothetical color-triplet bosons carrying both lepton and baryon number. First-generation scalar leptoquarks ($\mathcal{S}_1$) are assumed to decay through $\mathcal{S}_1 \to eq_1$ with $BR = \beta$ and $\mathcal{S}_1 \to \nu_e q_1'$ with $BR = 1 - \beta$. First-generation leptoquarks with a mass of about 200 GeV/c^2 have been suggested by the H1[10] and ZEUS[11] experiments as a possible explanation for an excess of large Q^2 events. CDF[12] has searched for the process:

$$p\bar{p} \to \mathcal{S}_1\bar{\mathcal{S}}_1 + X \to (e^- q_1)(e^+\bar{q}_1) + X. \tag{8}$$

In the event selection, we require two isolated electrons with $E_T > 25$ GeV, one in the central region and a second one in the central or plug region, and two high-$\mathrm{E_T}$ jets, one with $E_T > 30$ GeV and a second one with $E_T > 15$ GeV. The main background is Drell-Yan processes: $Z/\gamma \to e^+e^- + \geq 2$ jets. We eliminate $Z \to e^+e^-$ by requiring the invariant mass of the two electrons to be outside the Z mass window ($76 - 106$ GeV/c^2). To eliminate Drell-Yan continuum, we cut also on the $\sum E_T$ of electrons and jets: $E_{Te1} + E_{Te2} > 70$ GeV and $E_{Tj1} + E_{Tj2} > 70$ GeV.

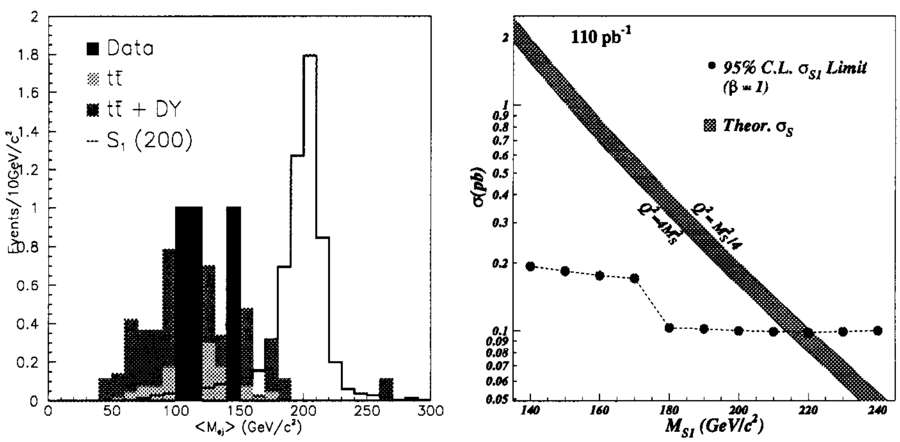

Figure 6: (left) $\langle M_{ej} \rangle$ distribution. The line histogram is the expected distribution for $M_{\mathcal{S}_1} = 200$ GeV/c^2. (right) The 95% C.L. upper limit on the $\mathcal{S}_1\bar{\mathcal{S}_1}$ cross section.

For the signal, the invariant masses of the two electron-jet pairs are expected to be close. We reconstruct the electron-jet invariant masses (M_{ej}) choosing the pairing that gives the smallest mass difference. We select events with two M_{ej}'s balancing with each other within two 2σ in the mass difference resolution. We find 3 events passing the cut. For each event, we calculate the mean invariant mass, $\langle M_{ej} \rangle$. The $\langle M_{ej} \rangle$ distribution is shown in Figure 6. Also shown are the expected distributions for Drell-Yan and $t\bar{t}$ backgrounds and the expected signal distribution for $\mathcal{S}_1$ of mass 200 GeV/c^2, using the NLO cross section of Krämer *et al.*[13]

The data shown in Figure 6 are used to set a limit on the $\mathcal{S}_1\bar{\mathcal{S}}_1$ production cross section versus the $\mathcal{S}_1$ leptoquark mass $M_{\mathcal{S}_1}$. The number of candidates for a given $M_{\mathcal{S}_1}$ is defined as the number of observed events with $\langle M_{ej} \rangle$ in a $\pm 3\sigma$ interval around that mass, σ being the mean mass resolution. The total efficiency varies between 23% ($M_{\mathcal{S}_1} = 140$ GeV/c^2) and 28% ($M_{\mathcal{S}_1} = 240$ GeV/c^2). The total systematics is about 13%. From these we calculate the 95% C.L. upper limit on the $\mathcal{S}_1\bar{\mathcal{S}}_1$ cross section. See Figure 6. From this we obtain: $M_{\mathcal{S}_1} > 213$ GeV/c^2 for $\beta = 1$ at 95% C.L. A similar limit has been obtained by the D0 experiment.

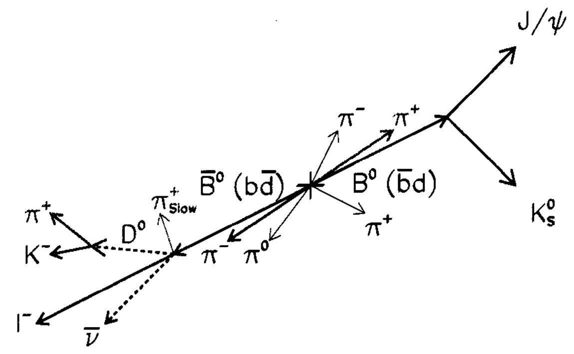

Figure 7: An illustration of B decays.

3 B^0-$\bar{B}^0$ Mixing

The probability that a B^0 meson produced at $t = 0$ decays as a B^0 or $\bar{B}^0$ at a proper time t is given by

$$\begin{aligned} P(t)_{B^0 \to B^0} &= \tfrac{1}{2\tau} e^{-\frac{t}{\tau}} (1 + \cos\Delta m t) \\ P(t)_{B^0 \to \bar{B}^0} &= \tfrac{1}{2\tau} e^{-\frac{t}{\tau}} (1 - \cos\Delta m t) \end{aligned} \tag{9}$$

where τ is the lifetime and $\Delta m = m_H - m_L$ is the mass difference between the two mass eigenstates.

To measure B^0-$\bar{B}^0$ mixing (and CP violation), we must know whether a B^0 or $\bar{B}^0$ ($\bar{b}$ or b) was produced. There are several techniques for b flavor tagging. An illustration of B decays is shown in Figure 7. In the opposite side tagging, the flavor of a B meson at production is inferred from the second b hadron in the event, under the assumption that b and $\bar{b}$ quarks are produced in pairs. There are several varieties for this. We can use the charge of the lepton from the second b hadron; b ($\bar{b}$) is likely to produce l^- (l^+): soft lepton tagging. We can use a momentum-weighted sum of the charge of tracks in the second b hadron decay; b ($\bar{b}$) is likely to end up in the negative (positive) charge: jet charge tagging. On the other hand, in the same side tagging, we do not look at the second b hadron. We use charge correlations between the B meson of interest and charged tracks in its vicinity; $\bar{B}^0$ (B^0) is likely to be accompanied by π^- (π^+), and B^- (B^+) is likely to be accompanied by π^+ (π^-).

The flavor at decay is identified by decay products (lepton and D mesons). We measure the asymmetry $A(t)$ defined as

$$A(t) = \frac{N(t)_{\text{unmixed}} - N(t)_{\text{mixed}}}{N(t)_{\text{unmixed}} + N(t)_{\text{mixed}}}, \tag{10}$$

where $N(t)_{\text{unmixed}}$ ($N(t)_{\text{mixed}}$) is the number of unmixed (mixed) events in which the flavor at decay is identical to (different from) the flavor at production.

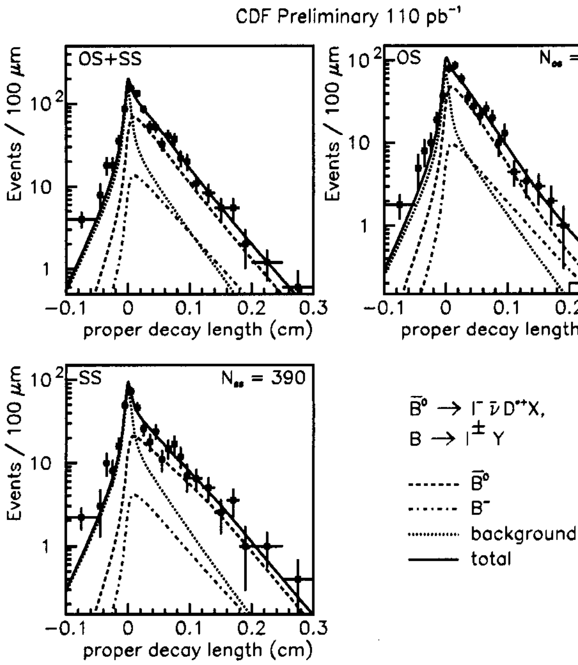

Figure 8: Proper decay length distributions for lepton + D^{*+} events in dilepton ($e\mu$, $\mu\mu$) data using soft lepton tagging.

In an ideal experiment, $N(t)_{\text{unmixed}}$ ($N(t)_{\text{mixed}}$) is proportional to $P(t)_{B^0 \to B^0}$ ($P(t)_{B^0 \to \bar{B}^0}$) and we have

$$A(t) = \cos\Delta m t. \tag{11}$$

In a real experiment, if the probability for mistagging the flavor is P_W, the observed asymmetry becomes

$$A(t) = (1 - 2P_W)\cos\Delta m t. \tag{12}$$

CDF has four measurements of B^0-$\bar{B}^0$ mixing, (1) lepton + $D^{(*)}$ events in single lepton data using same side tagging, [14] (2) lepton + inclusive vertex events in singe lepton data using jet charge and soft lepton tagging, (3) lepton + inclusive vertex events in $e\mu$ data using soft lepton tagging, and (4) lepton + D^{*+} events in dilepton ($e\mu$, $\mu\mu$) data using soft lepton tagging. [15] In the following, I will focus on (4) and show the results only for the first three.

We use a sample of data collected by the dilepton ($e\mu$, $\mu\mu$) triggers. The B meson decays are reconstructed using the decay mode:

$$\begin{aligned} \bar{B}^0 \to l^- \bar{\nu} D^{*+} X, D^{*+} &\to D^0\ \pi^+ \\ D^0 &\to K^-\pi^+, K^-\pi^+\pi^+\pi^-, K^-\pi^+\pi^0 \end{aligned} \tag{13}$$

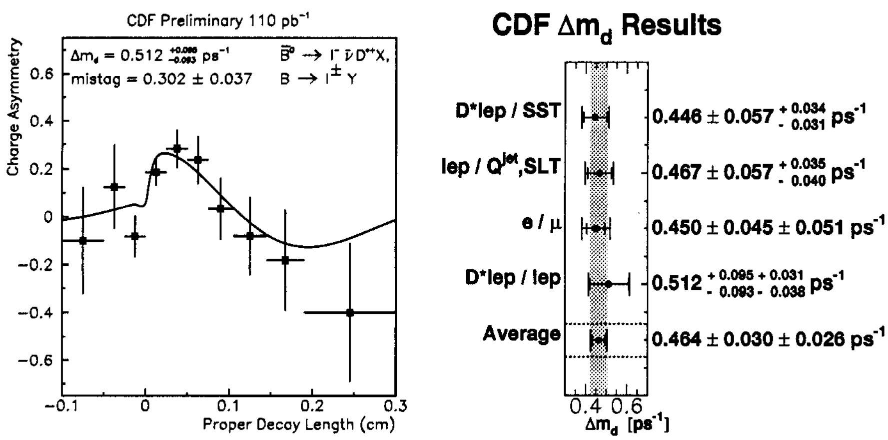

Figure 9: (left) Observed asymmetry $A(t)$ in lepton + D^{*+} events in dilepton ($e\mu$, $\mu\mu$) data using soft lepton tagging. (right) CDF Δm_d results.

and their charge conjugates. We first reconstruct a D^0 candidate and then combine it with a pion candidate to form a D^{*+} candidate. The B decay vertex is reconstructed from the lepton and D^{*+} tracks and is used to estimate the proper decay length.

The flavor at decay is identified by the sign of the final state ($l^- D^{*+}$ for $\bar{B}^0$ and $l^+ D^{*-}$ for B^0). The flavor at production is inferred from the charge of the second lepton in the event. An opposite sign (OS) lepton pair tags unmixed events and a same sign (SS) lepton pair tags mixed events.

The proper decay length distributions are shown in Figure 8. We fit OS and SS data taking account of finite resolution in the decay length determination, $\bar{B}^0$ meson $\beta\gamma$ smearing due to missing neutrino in semileptonic decays, mistag probability P_W, background, and B^- contamination. The background shape is determined using sideband and wrong sign combination events in the mass distribution. Our $l^- D^{*+}$ sample is not a pure sample of $\bar{B}^0$ but contains a $\sim$ 15% B^- contamination due to the B^- semileptonic decay to higher mass charm states $B^- \rightarrow l^- \bar{\nu} D^{**0}$, followed by $D^{**0} \rightarrow D^{*+} \pi^-$. The output of the fit is Δm and P_W. The fit results are superimposed in Figure 8. If you look closely at Figure 8, you can see a slight difference between the OS and SS distributions. That is the signal of B^0-$\bar{B}^0$ mixing. From Figure 8 we calculate the asymmetry $A(t)$ and plot it in Figure 9 (left). Oscillations are now clearly seen.

A summary of CDF Δm measurements is given in Figure 9 (right).

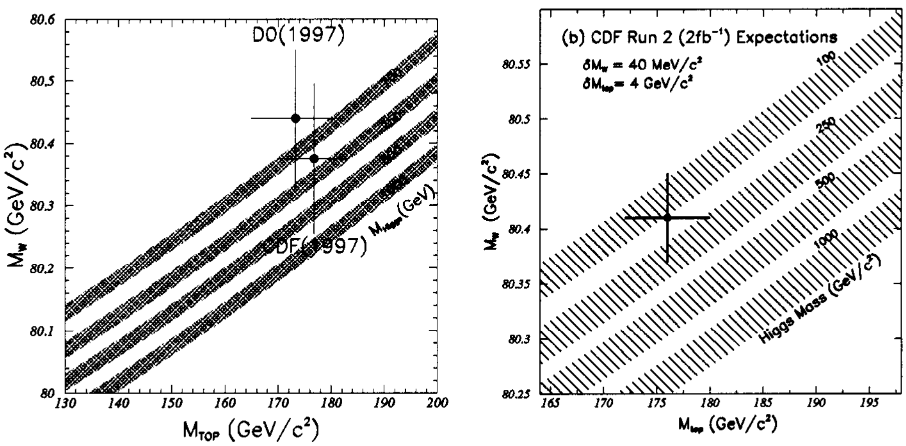

Figure 10: M_W vs M_{top}. (left) Run I results. (right) Expectations for Run II.

4 Prospects for Run II

The Tevatron collider Run II will start in March 2000. The Fermilab accelerator is being upgraded for Run II. The CM energy will be increased from 1.8 TeV to 2.0 TeV. The $\sigma_{t\bar{t}}$ at 2.0 TeV is expected to increase by a factor of 1.4. The integrated luminosity will be increased from 0.1 fb^{-1} to 2 fb^{-1}. The CDF detector is also under major upgrade. For instance, the acceptance for $t\bar{t} \to l + \geq 3$ jets will be increased from 9% to 11% and the SVX b-tagging efficiency from 39% to 65%, allowing us to collect 990 $l + \geq 3$ jet events with at least 1 SVX tag. The new detector is called the CDF II detector. [16] With these upgrades we will be able to pursue many exciting physics in Run II.

In top quark physics, we will measure the top quark mass to $\Delta M_{\mathrm{top}} < 4$ GeV/c^2, and the $t\bar{t}$ production cross section to $\Delta\sigma/\sigma \sim 9\%$, and perform detailed survey of top quark properties. In electroweak physics, we will collect 4.3M $W \to l\nu$ and 600K $Z \to l^+l^-$ events, where $l = e, \mu$. The W boson mass will be measured to $\Delta M_W < 40$ MeV/c^2. We will be able to seriously constrain the Higgs mass. See Figure 10. In QCD physics, we will be testing higher order QCD calculations using the production and fragmentation properties of jets, and the production properties of Drell-Yan lepton pairs, direct photons, W/Z bosons, and heavy quarks. In exotic physics, we will be searching W', Z', leptoquarks, excited quarks, quark-lepton compositeness, and SUSY particles in a significantly wider mass region. In B physics, we will collect 10K$-$15K $B^0 \to J/\psi K_s$ events and measure sin2β to Δsin2$\beta = 0.13 \sim 0.08$. We will collect $\sim$ 10K $B^0 \to \pi^+\pi^-$ events and measure sin2α to Δsin2$\alpha \sim 0.14$.

Measurements of B_s^0-$\bar{B}_s^0$ mixing and $\Delta\Gamma_s$ will allow us to determine $|V_{td}/V_{ts}|$ to $\Delta|V_{td}/V_{ts}| \sim 0.20$, thus over-constraining the CKM unitarity triangle.

The Run I with the CDF detector was quite successful. The Run II with the CDF II detector will be even more successful. We are working to make it.

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